A bridge between liquids and socio-economic systems: the key role of interaction strengths

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Abstract One distinctive and pervasive aspect of social systems is the fact that they comprise several kinds of agents. Thus, in order to draw parallels with physical systems one is lead to consider binary (or multi-component) compounds. Recent views about the mixing of liquids in solutions gained from neutron and X-ray scattering show these systems to have a number of similarities with socio-economic systems. It appears that such phenomena as rearrangement of bonds in a solution, gas condensation, selective evaporation of molecules can be transposed in a natural way to socio-economic phenomena. These connections provide a novel perspective for looking at social systems which we illustrate through some examples. For instance, we interpret suicide as an escape phenomenon and in order to test that interpretation we consider social systems characterized by very low levels of social interaction. For those systems suicide rates are found to be 10 to 100 times higher than in the general population. Another interesting parallel concerns the phase transition which occurs when locusts gather together to form swarms which may contain several billion insects. What hinders the thorough investigation of such cases from the standpoint of collective phenomena that we advocate is the lack or inadequacy of statistical data for, up to now, they were collected for completely different purposes. Most essential for further progress are statistics which would permit to estimate the strength of social ties and interactions. Once adequate data become available, rapid advance may be expected.

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Preliminary version, comments are welcome

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1 Introduction

Over the past decade econophysics and sociophysics have been developed by theoretical physicists who mainly came from statistical physics. Recent research in econophysics comprised a large body of empirical inquiries on topics which so far had been largely ignored by economists or sociologists. In addition, a number of theoretical tools developed in polymer physics, spin glass studies, Ising model simulations or discrete scaling were tentatively applied to problems in economics and sociology. This paper develops the idea that there is a connection between some of the phenomena studied in statistical physics and processes which occur in human societies. If persuasive, that argument would strongly support the claim (which is at the core of econophysics) made by physicists that the insight they have gained in studying physical systems can indeed be of value in the social sciences as well. Apart from this broad contention, our investigation will also tell us which phenomena are most likely to provide a good starting point for studying social systems in a fruitful way.

In the course of this paper we will see that it is the liquid state which seems to provide the best bridge to social systems. This is easy to understand intuitively. Crystallized solids have a structure whose regularity and symmetries have no match in social systems. On the other hand gases are characterized by a complete lack of structure which does not match social networks. With their non trivial and adaptive intermolecular interactions, liquids and more specifically solutions offer a better analog to socio-economic systems. Glasses, that is to say solids without crystal structure, could also be possible candidates but in the present paper we restrict our attention to solutions. Subsequently we give other, more technical, arguments in favor of a parallel between solutions and social systems.

Unfortunately, the liquid state is probably the less well understood. It has been suspected for a long time (see for instance Moelwyn-Hughes 1957) that the departure from ideal (or even regular) solution behavior is due to the formation of complex molecular assemblages even for non-ionic solutions. This was the central assumption on which Dolezalek's theory was based; however it is only in recent decades, that neutron and X-ray scattering as well as infra-red spectroscopy provided a more accurate picture of such molecular clusters. The new picture which progressively emerged from these studies gave us an insight into microscopic mechanisms at molecular level. It is at this level that the parallel with social systems becomes closer and more natural. That is why, throughout this paper, we try to stick to molecular mechanisms and refrain from using such concepts as entropy, energy or temperature which become meaningful only at macroscopic level. So far, these concepts have no clear equivalent in social systems which, by the way, is not surprising for in a similarly way at molecular level the only notions which make sense are those of distance and molecular attraction, stretching and vibrations, molecular assemblage, and so on. In the first part of this paper I describe some physical phenomena involving solutions in terms which can be easily transposed to social systems; in the second, I invite the reader to take the plunge and outline some social parallels.

The paper proceeds as follows. In the second section, I recall that the key variable which accounts for a whole range of phenomena as diverse as boiling temperature, vapor pressure, surface tension, or viscosity is the strength of the intermolecular interaction. This is particularly true in the liquid state. That observation is a strong incentive to develop methods for measuring the strength of social ties. Once the prime importance of intermolecular coupling has been recalled, I describe what I call a paradigm experiment because it provides so to say a blueprint for future studies of social systems. This and similar experiments with solutions suggest that seeing the mixing of two liquids merely from the point of view of entropy as an irreversible operation which increases disorder prevents us from seeing the major role played by amalgamating and combining, two mechanisms which play a key role in both biological and social phenomena. In section 4, I consider the phenomenon of suicide in situations in which one has good reason to expect a low level of social interaction and, accordingly,

high suicide rates. Then I devote a few words to social or biological situations which are similar to gas condensation or solvation. Needless to say, each of these phenomena would deserve a more detailed study. Our objective in this paper is to draw a possible agenda for future research rather than to offer detailed case-studies.

Part I Physical background

Studying social phenomena is often frustrating because for each law or regularity that one tentatively tries to propose there are usually many exceptions and outliers. The situation is fairly similar in physical chemistry. No model has a broad validity and exceptions abound even for the most basic effects. In that sense physical chemists are certainly better prepared to cope with social systems than for instance particle physicists or solid state physicists. Our background presentation in the first part is entirely based on experimental evidence; the main reason for avoiding theoretical concepts is the fact that they cannot be easily adapted to social systems. The discussions I have had with the colleagues in my lab convinced me that even experienced theoretical physicists may not necessarily be familiar with those facts and interpretations; however, this first part may be safely skipped by physical chemists.

2 The key role of interaction strengths

In statistical physics we know that, at least in principle, the properties of a system may be derived from its Hamiltonian. However, for systems like liquids this can only be done with great difficulty and often only numerically. The point we want to make in this section is much simpler. We show that the behavior of a system to a large extent depends only on the *strength* of the interaction; its precise form, whether it is a coupling between ions, permanent dipoles, induced dipoles or a mix of those interactions does not really matter from an experimental point of view. In what follows the interaction strength will be our key parameter. It has by the way a simple geometrical interpretation in the sense that there is a close relationship between interaction strength and length of intermolecular bonds.

Before looking at more elaborate properties we first consider the state, whether solid, liquid or gas, in which a compound is to be found at room temperature. At first sight our claim that it is determined by the coupling strength could seem utterly wrong. Compare for instance H_2O and H_2S; while the first is a liquid, the second is a gas (boiling temperature = -60 °C) Yet, these molecules could be expected to be fairly similar for sulfur and oxygen are in the same column of Mendeleev's periodic table. Perhaps an even more striking apparent counter-example is ethanol and methyl ether which both correspond to the formula C_2H_6O. Whereas the first is a liquid (boiling point = 78 °C), the second is a gas (bp=-24 °C). Thanks to the thorough and patient work of physical chemists, we now know that the interactions between H_2O molecules is indeed much stronger than the one between H_2S molecules and similarly for ethanol and methyl ether molecules. It would take us too far away from the main purpose of this paper to explain the reasons of these differences. The main point we want to emphasize is that, in contrast to mainstream ideas in the 1910s (see for instance Holmes 1913) overall properties such a size, mass or composition of molecules turned out to be completely inadequate to explain their properties; that could be done only once experimental methods had been developed which could provide reliable estimates of intermolecular coupling.

Building on this knowledge we present in Fig.1a some data which illustrate the key role of the coupling strength.

Apart from the outliers to which we come back below, the graph concerns only hydrocarbons and

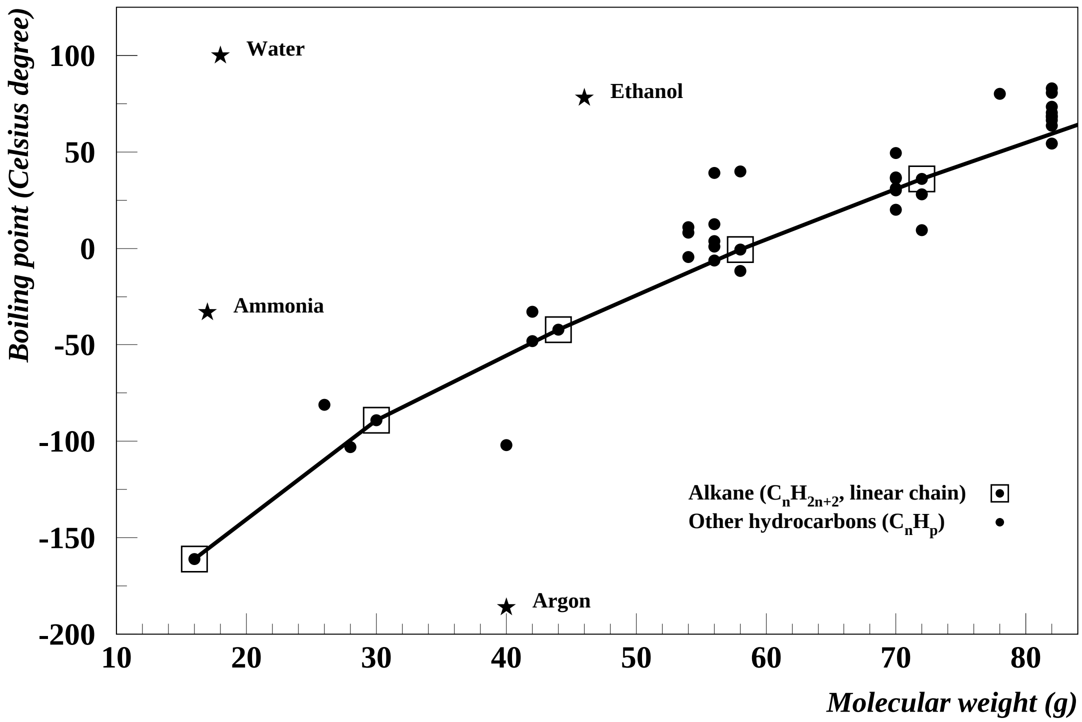

Fig.1a: Boiling temperature as a function of intermolecular attraction. For alkanes C_nH_{2n+2} with a linear chain, which are represented by dots surrounded by a square, the inter-molecular attraction is proportional to the number of the hydrogen atoms and hence also to the molecular weight $M = 14n + 2$. The trend portrayed by the solid line means that for longer carbon chains more thermal agitation is required in order to break the intermolecular bonds. The dots represent hydrocarbons C_nH_p whose intermolecular forces, are slightly different due for instance to branched carbon chain which results in boiling temperature differences of the order of 10%. The stars correspond to compounds whose molecular coupling are of a different nature, either much weaker (argon) or much stronger (ammonia, ethanol, water). *Source: Lide (2001).*

more particularly alkanes: C_nH_{2n+2}. As is well known, alkane molecules interact only trough dipole-induced forces, the so-called London dispersion forces. These fairly weak forces exist between any pair of atoms. As a result the interaction between two alkane molecules is basically proportional to the length of the carbon chain that is to say to the number n or in other words to the molecular weight of the alkane. The square correspond to experimental data for linear alkane chains, whereas the dots correspond to other hydrocarbons. Of particular interest are the dots which correspond to isomers (same molecular weight) of a given alkane. These isomers have ramified carbon chains, a feature which to some extent changes the London forces between the molecules and results in differences of the order of 10% (when temperatures are expressed in Kelvin degrees). The stars show a number of cases characterized by different kinds of interactions. As we know both water and ethanol, $CH_3 - CH_2 - OH$ have a dipole O_-H_+ which causes a fairly strong interaction trough so-called hydrogen bonds. At the bottom of the graph the single atoms of argon have almost no interaction at all which results in a very low boiling point close to -200 °C. Incidentally, it can be observed that there is a close relationship between bond strength and bond length. For instance if we assume a potential corresponding to a ion-ion attraction and a hard core repulsive force proportional to $1/r^p,\ (p \sim 9)$ the strength s of the bond is related to the distance R between the two ions by the relation:

$$s = \left.\frac{d^2V}{dr^2}\right|_{r=R} = (p-1)\frac{e^2}{4\pi\epsilon_0}\frac{1}{R^3}$$

In order to show that the previous argument extends to many other physical properties we show in Fig.1b that the enthalpy of vaporization and the viscosity of alkanes is again determined by the strength of the intermolecular forces that is to say in this case by the molecular weight. As it would be pointless to compare the viscosity of gases with that of liquids we restricted the latter curve to the alkanes which are liquid at room temperature.

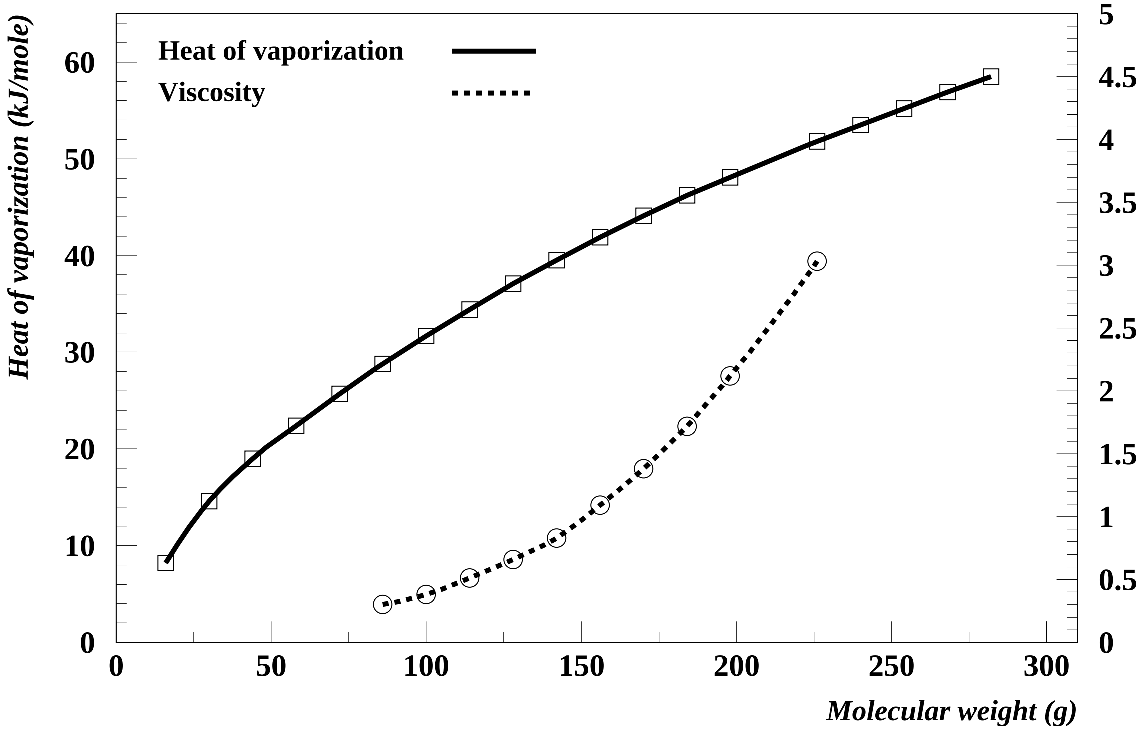

Fig.1b: Latent heat of vaporization and viscosity as a function of inter-molecular attraction for alkanes. As explained in Fig.1a, there is a direct relationship between attraction strength and molecular weight. The solid line corresponds to the 20 first alkanes (except $n = 15$ which is missing in data tables); it describes the empirical relationship: $L_s(\mathrm{C}_n\mathrm{H}_{2n+2}) = 1.1 + 1.7n$. The broken line represents the viscosity; it is restricted to the alkanes which are liquid at room temperature, namely $n = 7, \ldots, 16$ ($n = 15$ is again missing). *Sources: Lide (2001), Moelwyn-Hughes (1961, p.702).*

The relationships displayed by the curves in Fig.1a,b have a clear intuitive interpretation. The stronger the interaction, the better the molecules are held together and the more kinetic energy it takes to disrupt the molecular assemblages that make up solids or liquids. In the same way, in a liquid with a strong interaction only the fastest molecules will be able to escape which translates into a low vapor pressure. As to viscosity, a strong interaction will make neighboring layers to stick more closely together which for liquids results in a higher viscosity.

In order to test this way of reasoning let us see if we can use it in order to predict the relationship between interaction strength and other physical properties such as for instance the speed of sound. For sound to propagate, successive layers must be put into motion. Due to inertia, in order to put one layer into motion the main factor is the weight of the molecule. If there are strong bonds between molecules two things will happen.

- In a given layer, the inertia effect will be increased because strongly coupled molecules will somewhat behave as a cluster of molecules that is to say a super molecule of greater molecular weight.
- The transmission of the perturbation from one layer to the next will be facilitated.

Which one of these effects will prevail is not obvious. Observation shows that the first effect prevails in gases. Thus, by comparing the speed of sound in methane, CH_4, and propane, C_3H_8, we see that it is smaller in propane even after the factor $\sqrt{M}$ due to the molecular weight has been corrected for. In other words, for gases the speed of sound decreases with stronger interactions. On the contrary, in liquids and solids it is the second effect which prevails as illustrated by the two following examples[1]. (i) The speed of sound in pentane, C_5H_{12} is 1012 m/s (at 25 °C and 1 bar); thus, on account of its higher molecular mass one would expect a smaller velocity for heptane, C_7H_{16}, yet it is higher at 1129 m/s. (ii) As one knows, diamond, a solid with very strong interatomic bonds has a velocity of sound of 12,000 m/s, one of the highest to be observed in any substance.

The previous discussion shows that even in cases where the physical consequences of a strong interaction are less transparent than in the cases of Fig.1a,b, this factor nevertheless plays an essential role. In the next section we examine the role of interaction strengths in the mixing of two liquids.

3 The mixing of two liquids

The mixing of two liquids is described in Fig.2a. To call this a paradigm experiment could seem an inflated expression for such a modest experiment. Nevertheless, we will see that it carries a number of important ideas. Accurate experiments of this kind were carried out in the early 20th century in particular by the German physicist Emil Bose (1907). The experiment described in Fig.2a does not aim at precision, its objective is rather to give an intuitive feeling of the phenomenon. The upper line in Fig.2a shows that after being mixed the volume of a solution of water and ethanol, $CH_3 - CH_2 - OH$ decreases. The experiment provides a rough estimate of the contraction which is of the order of 2%. The lower line shows that the mixing phenomenon is exothermic. Naturally, the quantity of heat which is released would not be the same for another alcohol such as methanol, $CH_3 - OH$, or propanol, $CH_3 - CH_2 - CH_2 - OH$. A more detailed picture is given in Fig 2b. Bose's results furthermore show that when the experiment is carried out at 43 °C the mixing becomes endothermic as soon as the molar proportion of propanol becomes higher than 15%.

Having presented the facts, let us now see what can be learned from them and why this experiment is of interest for social phenomena. We will proceed from macroscopic to microscopic level.

1) From what has been said in section 1, it is obvious that the contraction and temperature increase are related. The contraction shows that intermolecular attraction in the solution is on average stronger than in the pure compounds. As the molecules rearrange themselves in line with the new interactions, energy is released in the same way as when an expanded spring returns to its equilibrium length[2].

2) What has thermodynamic to say about the mixing of liquids? Because the mixing is exothermic we know that the solution is not an ideal solution. The heat of mixing is given in terms of partial

[1]Let us recall that for all materials, whether gas, liquid or solid, the speed of sound is given by $c = \sqrt{E/\rho}$ where ρ is the density and E the bulk modulus of elasticity $E = \Delta\text{pressure}/[\Delta\rho/\rho]$ which basically describes the hardness of the material. In the case of a gas E can be expressed as the inverse of the (adiabatic) compressibility $E = 1/[(\Delta V/V)/p]$ where V and p denote volume and pressure respectively. In the case of a solid E is usually referred to as Young's modulus. In short, the above formula says that the speed of sound is larger in harder or lighter materials.

[2]Yet, there are cases where exothermic mixing is accompanied by a dilatation instead of a contraction, for instance in in the mixing of ethyl acetate, $CH_3 - \overset{\overset{\displaystyle O}{\|}}{C} - O - CH_2 - CH_3$, and carbon disulphide, $S = C = S$. It is true that the dilatation is fairly small (only 0.03%) but this exception nevertheless illustrates our previous reflexion about the difficulty in this field of stating rules which hold without any exception.

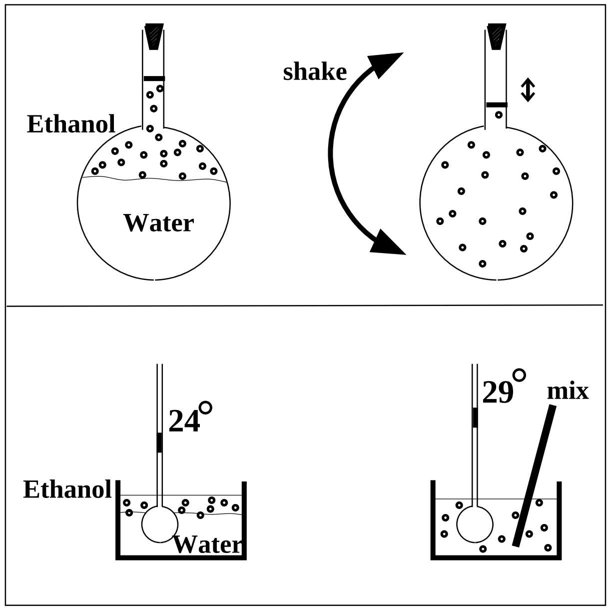

Fig.2a: Two experiments on the mixing of water and ethanol. Not just for fun …These are not *Gedanken* experiments, they can be performed easily by any theoretical physicist who wants to get a more intuitive feeling of the mechanisms described in this paper. When ethanol is added to water there is both a volume contraction and a release of heat. Both phenomena are affected by respective proportion and temperature. As predicted by LeChatelier's principle, the effect of a temperature decrease is to increase the heat of mixing. Similar experiments can be performed with many other compounds. The mixing of acetone (C_3H_6O) and chloroform ($CHCl_3$) is even more exothermic, whereas the mixing of acetone with carbon disulphide (CS_2) is strongly endothermic and results in a volume increase. Note that because carbon disulphide is more toxic and dangerous to handle (it catches fire very easily) than the previous compounds, the last experiment should rather be done in a chemistry lab. *Source: Moelwyn-Hughes (1961, p. 812).*

pressures by a formula first proposed by Nernst (Bose 1907, p. 621):

$$Q_{\text{mix}} = -RT^2 \frac{d}{dT} \left[x \log \frac{p_a}{p'_a} + (1-x) \log \frac{p_b}{p'_b} \right] \tag{3.1}$$

where T denotes the Kelvin temperature, x the molar proportion of water, $p_a,\ p'_a$ the pressure of vapor over pure water and over the solution respectively and $p_b,\ p'_b$ the same partial pressures for alcohol. When Raoult's law applies $p'_a = xp_a$ and similarly $p'_b = (1-x)p_b$ which means that the terms between square brackets become independent of T and, as a result, $Q_{\text{mix}} = 0$. This is the ideal solution case. For non-ideal solutions, the application of the above formula requires detailed input information about how the partial pressures depend upon temperature.

3) An interesting question is to understand the location of the peaks in Fig.2b. Why, for instance is Q_{mix} maximum for a proportion of 5 molecules of water for one molecule of ethanol? This leads us to examine the phenomenon at molecular level.

4) Thanks to the extensive work done by physical chemists we now have a better understanding of the mixing of liquids at molecular level. Of cardinal importance in the case of ethanol and water is the fact that the ethanol molecule $CH_3 - CH_2 - OH$ comprises two sections which react to water molecules in very different ways. The OH segment holds a dipole O(-)H(+) which can link up with the O(-)H(+) dipoles of the water molecules. The segment $CH_3 - CH_2$, on the other hand, is similar to ethane $CH_3 - CH_3$ and we know that ethane like any alkane is miscible in water in very small proportion only. As a result, this segment could seem to be irrelevant as far as the mixing with water

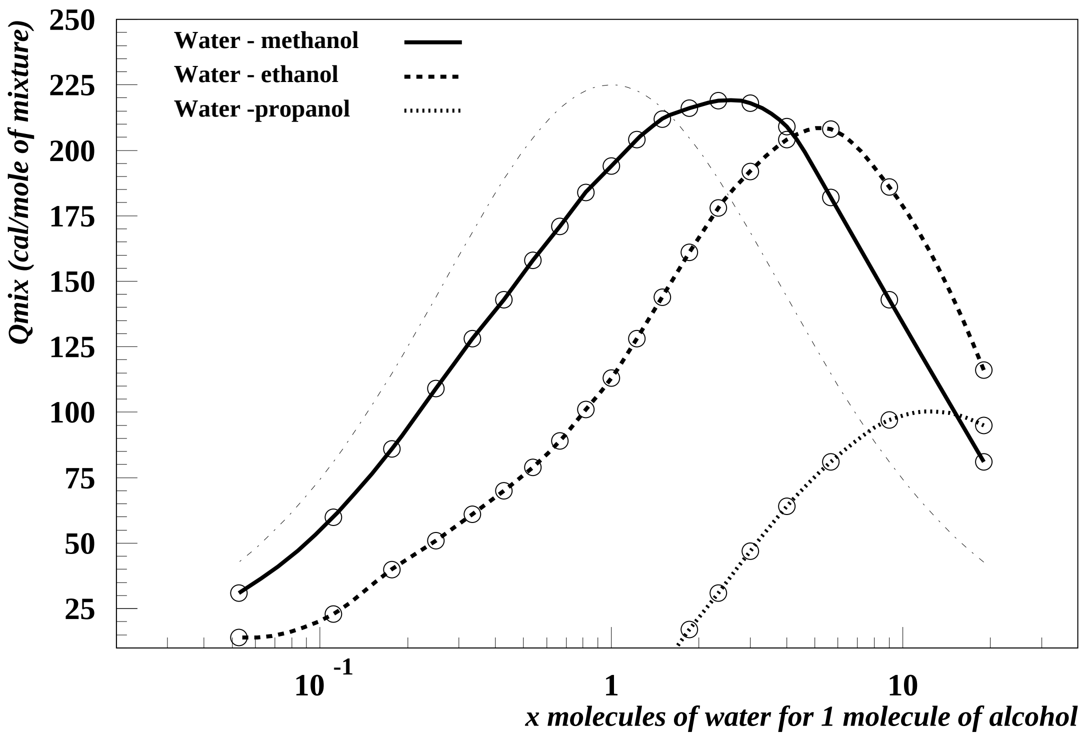

Fig. 2b: Heats of mixing: water - alcohols. Methanol, ethanol and propanol are the first three alcohols: $C_nH_{2n+1}OH$, $n = 1, 2, 3$. Usually, for instance for acetone-chloroform or methanol-ethanol, the corresponding curves are symmetrical with respect to molar concentration (as indicated by the thin line curve); this points to a a connection between the shape of the curves and the structure of molecular assemblages: the dissymmetry shows that several water molecules surround each alcohol molecule. Note that when the proportion of water becomes too small, the mixing with propanol becomes endothermic. *Source: Bose (1907), Landolt-Börnstein (1976)..*

is concerned. This, however, would be a simplistic view. Neutron and X-ray scattering experiments have shown that water molecules form a kind of net around alkane molecules in solution (Schmid 2001, Baumert et al. 2003)[3]. The molecular assemblage between water and ethanol molecules is described schematically in Fig. 3. The solid lines represent the dipole-dipole bonds while the dashed lines represent the weaker bonds between induced dipoles. One should bear in mind that these bonds and indeed the whole assemblage are rearranged on a picosecond time scale. In other words any representation such as the one in Fig. 3 can be nothing but an average view of a rapidly changing structure. In dynamical terms the mixing can be described by the following reaction:

$$x\mathrm{H_2O} + y\mathrm{C_2H_5O} \overset{\longleftarrow}{\longrightarrow} \left(x\mathrm{H_2O}, y\mathrm{C_2H_5O}\right) + Q_{\mathrm{mix}}$$

where, according to Fig. 3, x is of the order of 4-5 and y of the order of one[4]. Specific details, and in particular the exact values of x and y are anyway unimportant for the present discussion. The central point is that the mixing creates a new molecular assemblage and that this structural rearrangement basically results in an entropy *reduction*. Furthermore, it is of interest to observe that while the solution has a greater cohesion than the initial compounds, it is also characterized by a greater molecular

[3]Such a structure is often referred to as a clathrate, a synonym to hydrate which comes from the oil industry and designates compounds formed of ice in which molecules of hydrocarbons are trapped. Such compounds form in pipelines which cross cold regions and are also assumed to exist on some of the satellites of Jupiter or Saturn.

[4]In the framework of this reaction, the fact mentioned previously that Q_{mix} decreases when the temperature is increased becomes a simple consequence of the Le Chatelier principle for equilibriums. Indeed, in order to oppose the temperature increase the reaction must become less exothermic which means that the equilibrium is shifted to the left.

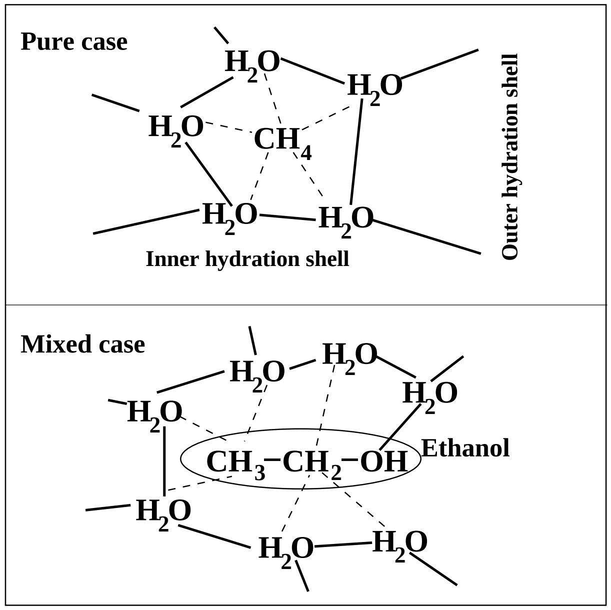

Fig. 3: Schematic representation of the molecular assemblage in water-methane and water-ethanol solutions. In contrast to methane CH_4 which features only weak London dispersion forces, the molecule of ethanol comprises two segments (i) the alkane-like segment $CH_3 - CH_2$ (ii) the water-like end OH. For that reason, ethanol displays a dual behavior: like methane, it attracts an hydration shell of water and like water it forms strong hydrogen bonds. According to some recent studies (Dill et al. 2003, p. 581) there may be as many as 17 water molecules in the first hydration shell. The precise shape of the molecular assemblage is of little importance for the purpose of this paper; what matters is the fact that it is a highly ordered arrangement. *Sources: Baumert et al (2003), Dill et al. (2003), Dixit et al. (2002), Guo et al. (2003), Israelachvili et al. (1996)*.

agitation. The simultaneous occurrence of higher cohesion and increased agitation is also observed in biological and social systems. It is particularly spectacular in the formation of swarms of locusts which we briefly discuss below.

We said that Fig. 3 is based on scattering experiments which permit direct observation. However, it can also be justified by indirect arguments. We mention that way of reasoning because it was the main approach in use during several decades between 1905 and 1945. By measuring specific physical variables for various compounds and by comparing these observations, physical chemists tried to gain a better understanding of the processes taking place at molecular level (see for instance Holmes 1913 or Earp and Gladsstone 1935). In the present case, this kind of reasoning can be illustrated as follows.

- In order to see if our point about the roles of the two segments in the ethanol molecule is correct, it is natural to examine what happens when one of the segments becomes preponderant. When the hydrocarbon chain becomes longer one would expect the alkane character of the molecule to become more pronounced. This is indeed confirmed by comparative observation for ascending members of the alcohol family, $C_nH_{2n+2}O$. For $n = 1, 2, 3$ the alcohols are soluble in water in all proportion which indicates the formation of strong links. However, starting with $n = 5$, the solubility is greatly reduced which shows that the alkane character becomes predominant; for $n = 4, 5, 6$ solubility is 0.11 g/ mole, 0.03g/mole and 0.06g/mole respectively. The solubility of the $n = 6$ alcohol, namely hexanol, is in fact of the same order of magnitude as the solubility of the corresponding alcane, namely hexane, which is 0.001 g/mole. The alkane-type behavior of high order alcohols is also observed at the level of boiling temperatures. Whereas there is a huge difference of about $220\,°$K between the boiling temperatures of methanol and ethane, boiling temperatures of higher order alcohols tend

asymptotically toward those of the alkanes; thus for $n = 10$ the difference is reduced to less than $50\ °K$.

• Conversely a behavior which becomes close to that of water is observed when the role of the OH segment becomes predominant. Whereas for $n \geq 2$ all alcohols are soluble in hexane, methanol ($n = 1$) is only slightly soluble at 0.12g/mole. Similarly the role of the OH segment can be expected to be enhanced in di-alcohols or tri-alcohols, that is to say molecules that contain two or three OH segments. Thus glycerol,

$$\begin{array}{ccccc} \mathrm{OH} & & \mathrm{OH} & & \mathrm{OH} \\ | & & | & & | \\ \mathrm{H_2C} & - & \mathrm{CH} & - & \mathrm{CH_2} \end{array}$$

is soluble in water in all proportions but is almost not soluble in hexane [5].

Attempts to bridge the gap between statistical physics and socio-economic phenomena usually come up against two difficulties. The first one, which is not often mentioned, is the ergodic hypothesis to which we come back later. The second is the fact that the notions of entropy, energy or temperature which are so central in physics have no obvious counterpart in social phenomena[6]. That is why we carefully avoided using these notions. All the mechanisms described in this first part can be transposed to biological or social phenomena. This is the purpose of the second part of the paper.

Part II Social phenomena in the light of physics

The main challenge in this part is to identify those (if any) social phenomena which can be better understood in the light of the notions presented in the first part. Needless to say, many kinds of social phenomena do not fall into this category. For instance, cultural or gender studies draw on notions which have no parallels in physics. There are however many important socio-economic phenomena which can be interpreted along the lines used in Part I. One can mention the following.

• In the first part we emphasized the connection between interaction strength and molecular rates of escape from a liquid. Any system whose members are held together by some cohesion forces but may occasionally escape from the system would provide a possible parallel. Table 1 provides a number of examples.

For instance, if the system is a college or a university the retention rate of freshmen provides an indication about the balance between group cohesion and centrifugal forces. If the system is an army, the desertion or AWOL (Absent WithOut Leave) rates provide a global estimate of the resultant of many forces such as for instance patriotism, fear of being punished, conservation instinct, and so on. All the cases mentioned in table 1 would provide interesting testing fields for the interpretation that we advocated. Unfortunately, for most of them only scarce or fragmentary data are available. By a slight but natural extension it is possible to include suicide in the present category. The likelihood of not committing suicide represents a kind of retention rate. The main incentive for including suicide is the fact that in this case at least there are numerous statistical data. Naturally, suicide has been studied by sociologists for decades without any reference to physics; one may therefore wonder what difference it makes to adopt the present perspective. Instead of analyzing suicide statistics almost

[5] Although it has received great attention the question of solubility does not seem to have been solved in a completely satisfactory way from a theoretical perspective. Both the Hildebrand system and the more recent Teas graph system are mainly empirical with little theoretical justification. This, however, does not prevent them from being useful and fairly accurate tools. Incidentally, it can be noted that an important special case, namely the solubility of hydrocarbon polymers is well accounted for by the Flory-Huggins theory based on combinatorial counting. It does not apply to polar molecules however.

[6] As a matter of fact, this is not surprising for these are macroscopic variables which are neither “felt” nor “known” at molecular level.

Table 1 Retention dynamics in various institutions

Institution	Intra-institutional bonds	Type of escape
High school, college, university	Links with students, teachers, professors; attraction of qualified jobs	Dropout
Faith community, religious order	Links with rest of congregation, common faith	Decline in attendance
Army	Patriotism, discipline, renumeration	Desertion
Nation	Family ties, attraction of home country	Immigration
Society	Family ties, links with friends	Suicide

Notes: The fact that one often observes a conjunction of substantial high school dropout rates with high suicide rates among teens seems to show that the interactions which account for these effects overlap to some extent. As an illustration, for the Oglala Sioux who live on Pine Ridge Reservation, South Dakota, dropout and suicide rates among teens are 6 and 4 times higher respectively than in the general population; for American Indians overall, the dropout and teen suicide rates are 35 percent and 37 per 100,000, respectively 3 and 2.5 times higher than in the general population. In the second column we attempted to list some of the possible bonds that keep an individual attached to a given institution. This list, however, is more based on common sense than on genuine measurements. As a matter of fact, we do not yet know what is the respective importance of these links. For instance, we know that family ties are important in suicide, but we do not have a clear picture of the respective role of short-range versus long-range ties. What makes reliable measurements difficult is the fact that the level of exogenous shocks (which represent thermal agitation) is usually time-dependent and has therefore to be controlled for.
Sources: Reyhner (1992), Olson (2003), http://www.re-member.org

indiscriminately, the present perspective leads us to focus on situations where social ties are either very strong or very weak. By so doing we will be in a better position to grasp the key mechanisms (as opposed to incidental circumstances) of the phenomenon. The next section provides an introduction to this approach.

- The second physical phenomenon for which there are some natural biological and social parallels is the condensation of a gas, that is to say the transition from a state in which the molecules have low interactions to a state where they form an entity characterized by a substantial interaction and cohesion. Macromolecules, bacterias, protozoa, insects, animals or humans in certain conditions display a tendency to self-aggregation. Instead of considering each of these cases as separate it may help our understanding to look at them from a unified standpoint. We briefly discuss two cases which belong to this category of phenomena.
- The third physical phenomenon for which there is a natural sociological extension is the mixing of to liquids. Amalgamation of different populations is a mechanism of fundamental importance. Under that heading one can consider the amalgamation of populations of peasants, merchants and craftsmen. Through the links of cooperation and exchange that they establish, cohesion and productivity are greatly enhanced. Another important mechanism of amalgamation is the so-called melting pot mechanism by which a group of immigrants becomes integrated. Again, one may ask what benefit can be gained from considering these phenomena from the standpoint of statistical mechanics. In a physical solution the new bonds between solute and solvent are established in a matter of seconds

if the solution is mixed up by an external device, but it will take much longer if one has to rely on diffusion for the mixing process. Similarly, the time scale required by the amalgamation process very much depends upon the magnitude of the "mixing". It may take one or two generations in a city, but much longer in a mountainous region where population density is low and contacts are rare. This parallel shows that in order to understand the dynamics of bond formation one must adopt an adequate time scale. For urban integration, 50 years may be an acceptable time period, whereas for low density regions two or three centuries would be more suitable. In short, through the analogy with physical phenomena we get a better understanding of how to set up the inquiry.

4 Suicide in a population with weak ties

In the late 19th century there have been numerous studies about suicide in all European countries. The following references (arranged in chronological order) constitute a select sample of the publications of that period, along with some more recent ones: Boismont (1865), LeRoy (1870), Cristau (1874), Morselli (1879), Legoyt (1881), Masarick (1881), Nagle (1882), Durkheim (1897), Krose (1906), Bayet (1922), Douglas (1967), Baudelot et al. (1984). All these studies of course took advantage of the fact that thanks to the development of census offices extensive demographical statistics became available in all industrialized countries. Among the aforementioned authors, the contribution of Emile Durkheim stands out because, in contrast to most other authors, he was not interested in why individual people commit suicide but from the start considered suicide as a social phenomenon. In the very first sections of his book, he makes clear that to understand suicide one should examine the web of connections and affiliations each individual has with the people around him. For Durkheim it is the failure of family, church, community of neighbors to provide effective forces of social integration which is at the heart of the problem. In short, Durkheim's perspective is very close to the standpoint of statistical physics that we presented in part I. Unfortunately, his message has been largely discarded and forgotten, to the point that nowadays most studies center on individual psychological causes.

In support of his thesis Durkheim presents a great wealth of data for many different countries. However, for his argument to become really compelling and conclusive one would need a way to measure the strength of social ties in an objective and quantitative way. Instead Durkheim relies on common sense and intuition with the result that his proofs remain somewhat tautological. For instance, even if it is natural to admit that bachelors have fewer social (and especially family) ties than people who are married with several children, estimates based on an objective criterion would be needed. Otherwise the observation that suicide rates are higher among bachelors cannot be quite conclusive. We must confess that our own methodology will have the same defect, only to some extent mitigated by the fact that the situations that we consider are so extreme that in order to make sense our "common sense" estimates need only to have the right order of magnitude. This is why we focus on situations characterized by low levels of interaction. In the following we consider three situations of that kind.

4.1 People with schizophrenia

Schizophrenia is a severe mental illness characterized by a variety of symptoms including lost of contact with reality and social withdrawal. People with schizophrenia may avoid others or act as though others do not exist; for example they may avoid eye contact with others or may lack interest in participating in group activities. Clearly this is a situation where interpersonal links are severely weakened. It turns out that suicide rates among people with schizophrenia are 10 to 15 times higher than in the general population: a typical figure is 200 per 100,000 as compared to 15 per 100,000 in the general population.

4.2 Inmates

Persons who are arrested and jailed see links with family, friends, colleagues or neighbors suddenly severed. Of course, once in jail for some time, inmates are likely to build new ties for instance with other inmates, guardians, lawyers, chaplains or other persons who may assist them. One would expect, therefore, that it is in the first days in jail that the disaggregation of social ties is the most severely felt. This prediction is matched by observation. Indeed, it turns out that suicide rates are particularly high during the first few days in jail. A study performed in 1986 about jail suicide in the US found that 51% of the suicides which occur in jail (as opposed to prison which in the US designates facilities for stays of over one year) happen in the first 24 hours of incarceration. Thanks to official data which are available on the Internet for New York State (New York State 1998: Crime and Justice Annual Report, http://criminaljustice. state.ny.us) we are able to compute an order of magnitude of the suicide rate in short-term detention facilities technically known as “lockups” where detainees usually stay for less than 72 hours before being transferred to county jails. The reasoning goes as follows.
On a single day of 1998 the average number of detainees in lockups was 473 (151 for New York City and 322 for upstate New York). Naturally, these detainees were not the same throughout but this is irrelevant for the present calculation. Over the whole year there were 6 suicides (2 in New York City and 4 upstate) which gives a rate of $6/473 = 1268$ per 10^5. If the same calculation is done for each year between 1990 and 1999 one gets an average suicide rate of 903 per 10^5. Because, a great majority of inmates are males, this figure should be compared to the suicide rate of men in the general population of New York State which for the period 1990-1998 was 13.0 per 10^5. The suicide rate in the first 6 days of detention was therefore 69 times higher, This order of magnitude is consisted with results obtained by other studies which analyzed suicide rate in the first days of detention (table 2). As detainees form new links in jail, the suicide rate progressively declines. In county jail where inmates usually stay for periods of less than one year, the rate is about 10 times higher than in the general population. In state prisons, where inmates stay for periods of more than one year, the rate is almost the same as in the general male population.

Table 2 provides also data for some other countries. These data do not distinguish between short-term and long-term facilities. Most of the figures are between 100 and 200 which is consistent with the rates observed in US county jails.

How accurate and reliable are the data given in table 2? This is certainly an essential question. An official report (Hayes and Rowan 1998) found under-reporting of jail suicide in 1986 to be of the order 40 percent nationally, but with great differences between states. Thus, in New York State no under-reporting was identified (which is why we selected this state to compute the previous estimate), whereas in Alabama, Louisiana, Pennsylvania or Tennessee under-reporting was over 50 percent. As there are no reasons for and indeed no mention of over-reporting we can at least be assured that the figures which are made public provide trustworthy lower bounds.

In conclusion, the phenomena of suicide among people with schizophrenia or inmates seem to provide spectacular illustrations of the effect of a weakening of social ties on suicide (escape) rates. However these situations may be seen with good reason as somewhat artificial in the sense that these groups are subject to illness or special living conditions imposed from outside. This is why we now turn to situations which can be considered as more “natural” in the sense that they concern entire societies and occur every time “traditional” societies come into contact with societies which are technically more advanced.

Table 2 Suicide rates among inmates

	Type of institution	Time elapsed since incarceration (T)	Location	Time interval	Suicide rate [per 100,000]
1	Lockup	$T < 72$ hours	New York State	1990 – 1999	900
2	Lockup	$T < 72$ hours	South Dakota	1984	2975
3	Jail	72 hours $< T < 1$ year	Texas	1981	137
4	Jail	72 hours $< T < 1$ year	South Carolina	1984	166
5	Jail	72 hours $< T < 1$ year	US	1986	107
6	Jail	72 hours $< T < 1$ year	New York State	1986 – 1987	112
7	Prison	1 year $< T$	US	1984 – 1993	21
8	Not spec.	Not spec.	Belgium	1872	190
9	Not spec.	Not spec.	England	1872	112
10	Not spec.	Not spec.	Saxony	1872	860
11	Not spec.	Not spec.	Canada	1984 – 1992	125
12	Not spec.	Not spec.	New Zealand	1988 – 2002	123
13	Not spec.	Not spec.	England	1990 – 2000	112
14	Not spec.	Not spec.	France	1991 – 1992	158
15	Not spec.	Not spec.	Australia	1997 – 1999	175
16	Not spec.	Not spec.	Canada	1997 – 2001	102
17	Not spec.	Not spec.	Scotland	1997 – 2001	227
	Average (8-17)				**218**

Notes: As a useful yardstick one can use the suicide rate among males in the United States between 1979 and 1998 which was about 20 per 100,000. Suicide rates of inmates are highly dependent upon the time they have spent in prison since their incarceration. A detailed study based on 339 suicides that occurred in the US in 1986 found that 51 percent of the suicides occurred in the first 24 hours of incarceration. This observation is consistent with the interpretation of suicide as resulting from a severing of social ties. In the statistics published in other countries than the United States, the time of incarceration is not specified. However, since inmates incarcerated for less than one year are in greater number than those incarcerated for longer durations, one would expect the former to predominate. Therefore it is not surprising that the order of magnitude of suicide rates is more or less the same everywhere (one exception is Saxony).
Sources: 1: DCJS Report (tables 7,9,11); 2: Hayes et al. (p. 4); 3,4,5: Hayes et al. (p. 52-53); 6: DCJS Report (table 1), Hayes et al. (table 2); 7: http://www.mces.org/Suicide_ Prisons_ Jails.html; 8-10: Legoyt; 11: Correctional Service; 12: Corrections Department, http://www.corrections.govt.nz; 13: Her Majesty Prison Service; 14: Baron-Laforet, Bourgoin; 15-17: same as 12.

4.3 Traditional societies in situations of transition

Every time the social framework of a society undergoes overwhelming changes there is a time of transition during which the old structures no longer work or exist and those which are better adapted to the new situation have not yet emerged. As a result, one would expect such periods of transition to be characterized by a low level of social interaction. When two liquids mix the time it takes for the pattern of forces to rearrange and for the molecular structure to be reordered is probably to be counted in microseconds at the molecular level and in seconds at macroscopic level (provided the two liquids get mixed). In a society the transition may take decades. The figures in table 3 show that these situations are characterized by a substantial increase in suicide rates up to levels which are 3 to 4 times higher than in stable societies. These phenomena have many facets: familial, communal,

demographic, economic, political, etc. In the rest of this section we focus our attention on the case of Micronesia for which one has fairly good statistical data.

Table 3 Suicide rates in populations in a state of transition

	Population	Gender or age specification	Location	Time interval	Suicide rate [per 100,000]
1	Blackfoot		U.S.	1960 – 1969	130
2	Cheyenne		U.S.	1960 – 1968	48
3	Papago		U.S.	1960 – 1970	100
4	Indians	10 – 19	Canada	1986 – 1990	65
5	Natives	Male	Micronesia	1975 – 1990	50
6	Natives	Male, 15 – 24	Micronesia	1978 – 1987	129
7	Natives	Male, 15 – 24	Chuuk Islands	1978 – 1987	200

Notes: As a matter of comparison the average suicide rate in the United States over the period 1979-1998 was 12.2 per 100,000 for both genders, 19.5 per 100,000 for males and 20.7 for males aged 15-24. The area considered in cases 5 and 6 comprises the Federal State of Micronesia (Chuuk, Kosrae, Pohnpei, Yap), the Marshall Islands and Palau. Blackfoot, Cheyenne and Papago are three tribes of American Indians. Basically, either for North American Indians or in Micronesia the suicide rate of young adults is at least 4 times higher than in the general population.
Sources: 1-3: Lester; 4: http://www.hc-sc.gc.ca; 5-7: Rubinstein (2002)

Micronesia as it is defined by Donald Rubinstein (1994, 2002) from which we borrow most of the following information comprises the Marshall Islands, the Carolinas which now form the Federated States of Micronesia and the Northern Marianas. Most of these islands were occupied by Japan in 1914 and some of them were colonized by Japanese farmers. After World War II they became American Territories until they acceded to some form of autonomy in the late 1980s. In the 1950s and 1960s nuclear tests and missile tests were conducted at Bikini, Eniwetok and Kwajalein located in the Marshall Islands. While alcohol consumption by the islanders had been regulated or prohibited under Japanese rule, these restrictions were lifted in the 1960s. Moreover, thousands of US Peace Corps Volunteers arrived, schools were built in every island and the economy began to shift from a subsistence economy based on family gardening and fishing to an economy based on imported products and wage labor. Men played a central role in these two activities and their place in society was more affected than women's activities which centered around preparing food and taking care of the house and children. Yet, on Fig. 4 it can be seen that suicide rates increased for men as well as for women even if the latter did not exceed the level observed in industrialized countries.

How can we integrate and interpret these various changes in terms of social interaction? As we already noted, to do this in a satisfactory way would require either quantitative information about the frequency and intensity of interpersonal contacts and links, or a methodology (an equivalent to infra-red spectroscopy) that would enable us to estimate interaction strengths. However, we can make two observations which are fairly revealing at least quantitatively.

1) If interaction strength really plays a key role in this phenomenon, one would predict that the individuals who are most at risk are those who do not have strong family connections. That is true for suicide in a general way, but one would expect the effect to be much stronger in a situation where community bonds have been weakened. In such a situation the transition period between childhood, characterized by strong ties with parents, and adulthood, characterized by strong ties with one's own wife and children, is a particularly critical moment. In short, one would expect a high suicide rate

for young adults. This is indeed what observation shows (table 3). This effect is expected in any

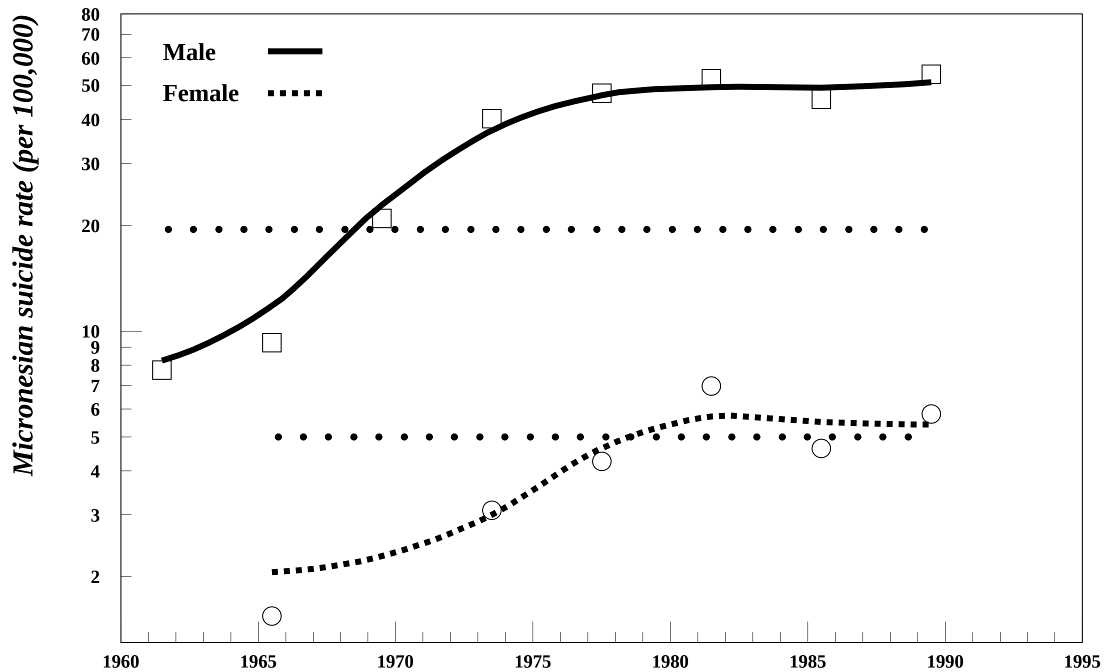

Fig.4: Suicide rate in Micronesia. The area covered by these data comprises the island of Palau, the Federated States of Micronesia (which includes the Chuuk islands) and the Marshall Islands. Concomitantly with the shift from a subsistence economy to one based on imported food and wage labor, there has been a huge increase in suicide rates for both men and women. The dotted horizontal lines show the American average suicide rates for men and women. The insert shows that it is the 15-24 age group which has by far the highest rate, a pattern which strongly differs from the age pattern in industrialized countries where it suicide rate increases with age. It is of interest to note that in Micronesia the high school dropout rate is around 40 percent that is to say four times more than in the United States. *Source: Rubinstein (1994, 2002), Hezel (2001)*.

society in transition, but in Micronesia it is to some extent amplified because of two local factors. As it is (or at least was) considered taboo for a sexually mature boy to sleep in the same house as his sisters, teenagers used to move to community men's houses which they would share with extended family relatives. But in many islands these community houses are no longer kept up with the result that young men do not have places where they can conveniently stay at this critical juncture. The second aggravating circumstance is related to the custom of adoption. In Micronesia, adoption was a widespread custom and a central pillar of family life. Like godfathers or godmothers but in a much stronger sense, the adoptive parents were a major constituent of the enlarged family. However, this institution has been imperiled both by the decay of traditional culture and by the rapid population growth. With a large number of children in each family there is much less incentive for adopting. The clear effect of the decay of adoption was to reduce the links between teenagers and adults.

2) Micronesia consists of more than 100 islands. As they have been affected to different degrees by social change we are in a good position for making comparative observations. Rubinstein (2002) mentions that suicide is less frequent in rural outer islands where traditional ways of life have to some extent be maintained. For instance, in the central island of Chuuk the average suicide rate of young males (15-24) was 207 per 10^5, whereas 500 kilometers to the east in the Pohnpei and Kosrae islands it was only 93 per 10^5.

At this point, we do not know if the factors that we have just described are really the main mechanisms

that account for the high suicide rates. In order to confirm (or confute) these conjectures other similar cases must be investigated in a comparative perspective.

5 Condensation phenomena

Particularly abundant rain in an area of central or northern Africa may result in a population of locusts which is in greater number than in ordinary years. It seems that once the density of locusts reaches a critical level a phase transition occurs which leads to the formation of swarms of locust which may contains billions of insects and have a duration of several years. In this process, locusts undergo slight physical changes (change in color, development of a gland for the release of a specific pheromone) which lead entomologists to describe them as a distinct subspecies (which they call a phase), namely *locust gregaria* as opposed to *locust solitaria* (Faure 1932). In order to better understand the factors which determine the transition from one phase to the other Jacobus Faure raised population of locusts in adjacent cages. It is worth reporting how he describes a cage containing *locust solitaria* in one half and *locust gregaria* in the other. "Whereas an individual isolated in one half of a cage leads a life of lazy idleness, its fellows in the other compartment separated by a gauze partition only, live a life of intense activity that could perhaps best be described as a frenzied effort to escape from some relentless, inwardly pursuing force." This observation suggests that the level of interaction and activity is greatly increased in the swarm state.

After having established that it is the crowding that leads to the formation of swarms, Faure went on to show that inter-specific crowding has the same effect as intra-specific crowding, In other words, the enhanced interaction that leads to swarm formation seems to be unconnected to a particular species of locusts.

The second example that we wish to mention of a transition analog to a condensation of a gas into a liquid is linked with the phenomenon of territorial conquest by clans of nomads that occurred repeatedly in central Asia. At least 5 episodes have been recorded by historians between the first and 17th century. In their "gaseous" state the clans wander more or less randomly over the vast land expanses of the steppe and have only minimal interaction with one another. Then, all of a sudden for no obvious reason, the various clans will gather around a leader whether it is Attila, Genghis Khan or Tamerlane. On such episodes our historical information is mostly limited to anecdotal evidence. We largely ignore the reasons which trigger these events[7] ; however, once started, it may have worked like a chain reaction in the sense that any battle won by the new leader strengthened and broadened his force of attraction and brought clans closer together. The physical analog would consist in following an isotherm on a (volume per mole, pressure) phase transition diagram; as one moves from the region of high volume per mole (i.e. low density) to lower volume per mole, one first sees some droplets of liquid form, and then, progressively, an ever larger proportion of gas becomes liquid until eventually all the gas is liquid. If this mechanism is correct, it means that the episodes of territorial conquest experienced by the nomadic tribes of Central Asia have been triggered by a major population increase.

[7]Demographic factors may have played an important role. Historians are not very informative on this aspect, but it is suggested almost as an evidence by Machiavelli (1469-1527), the Italian statesman and historian who lived in a time when the remembrance of Tamerlane (1370-1405) was probably still alive. In 1517 he wrote in his *Discourses on Livy*: "The other kind of war is when an entire people with all their families goes to seek a new seat in a new province. These people go out from their countries driven by necessity; and the necessity arises from famine, or war, and oppression, which in their own country is experienced by them. These people are almost all from the country of Scythia, a cold and poor place, where, because there were a great number of men and the country of a kind which was unable to feed them, they are forced to go out, having many things which drive them out and none to retain them." (adapted from the English translation of 1675, http://www.constitution.org/mac/disclivy_.htm).

What was the threshold density of population, in other words what is the upper density limit for nomadic people living on their livestock and occasional hunting. This is certainly an important parameter and in order to find its order of magnitude the most reliable procedure is probably to look at present day population density in regions where this mode of subsistence is still in effect. The following figures are for 1994 (i) The density of the vast area which comprises the Republic of Mongolia, Inner Mongolia (part of China) and Buryatia (a part of historical Mongolia now located in Russia) was 8.4 inhabitants per square kilometer. (ii) The density of Xinjiang in western China was 9.7 (iii) The density of the Chinese province of Qinhai which is located between Xinjiang and Tibet was 6.5. In all these cases the density of the grazing livestock was between two to three times the human density. To sum up, one can conclude that the upper density limit was around 8 people per square kilometer with about 2.5 head of livestock for each person. It should be noted that this limit is an upper bound but that the actual critical population density may have been somewhat lower. Once more population data about the previous historical episodes become available, it will be possible to say if our conjecture that they were driven by a common mechanism is indeed confirmed.

6 Multicomponent solutions and the melting pot mechanism

The integration of new immigrants is easier in large cities than in rural towns. Why? It is of course easy to provide a number of “anthropological” reasons such as better economic opportunities or the fact that the inhabitants of large cities are more used to the presence of various immigrants than the people in rural towns. Here we want to see whether our parallel with solutions can tell us something about this question. Two observations can be made in that respect.

- Roughly speaking, solubility requires that the molecules of the solute come in between the molecules of solvent and that new links are established between the former and the latter. For this to occur the interactions between solvent molecules should not be too strong whereas the solvent-solute interactions should be as strong as possible. Translated into sociological language, the fact that integration is easier in cities means that the interactions in cities (solvent) are weaker than in towns or that immigrant-city interactions are greater than immigrant-town interactions (both can conditions can be fulfilled simultaneously). Intuitively, these conditions seem to agree with common sense, but once again we are hampered by our inability to *measure* the strength of interactions.
- The previous discussion is not completely realistic because it considers a binary solution whereas in social situations there are several components. Although physical data handbooks contain less information about multicomponent solutions than about binary solutions, one aspect appears very clearly: multicomponent solutions are much less selective than binary components. What do we mean by the expression “less selective”? The heat of mixing curves for water-alcohol (Fig.1b) resemble resonance curves; the fact that there is a sharp fall on both sides shows that energetically the solvation is much less favorable as soon as one leaves the peak region; in other words the solubility is fairly selective. In contrast, for a multicomponent solution the heat of mixing curves are almost flat which shows that the solvation has a low selectivity. Intuitively, this is easy to understand for if the solution already comprises various molecules characterized by different kinds of bonds, it will be easy for any new molecule to link itself to one of them. This property of multicomponent solutions is illustrated in a more quantitative way in the following table.

The more components there are, the less changes in the molar proportion of one of the components perturbed the solution, as reflected in the fact that the heat of mixing becomes almost independent of the proportion.

Table 4 Relative selectivity of solvation according to number of components

	2 components	3 components	5 components
Coeff. of var. of Q / Coeff. of var. of proportion	77%	24%	12%

Notes: The table tells us that a solution with several components is less "selective" than a binary solution. The percentages give the ratio of the coefficient of variation (i.e. standard deviation divided by mean) of the heats of mixing, Q, relative to the coefficient of variation of changes in the proportion of one of the components. As an illustration, for water + ethanol (considered in Fig.1b) the ratio is for instance equal to 0.98. The 2-component figure is an average over three cases: water + methanol, water + ethanol, ethanol + toluene; the 3-component figure is the average of the two following cases: benzene + cyclohexane + hexane (proportion changes refer to hexane), benzene + cyclohexane + n-heptane (proportion changes refer to heptane); the 5-component case is: benzene + hexane + toluene + cyclohexane + heptane (proportion changes refer to heptane).
Source: Landolt-Börnstein (1976, p. 536-540).

7 Conclusion

Although I did not propose any model, time is not yet ripe for that, I hope this paper will help us to see a number of socio-economic phenomena in a more unified and less anthropocentric way. The potential usefulness of the parallels developed in this paper is that it gives us the incentive to compare phenomena which at first sight seem to have little in common. In this concluding section I would like firstly to discuss the question of ergodicity, an important theoretical issue on which depends the applicability of statistical mechanics, and secondly to suggest an agenda for future research.

7.1 Does the ergodicity hypothesis hold for socio-economic systems?

The success of statistical mechanics is entirely based on the fact that ensemble averages can be identified with time averages. On the theoretical side we compute the most probable configurations of the system on the basis of a collection of similar systems characterized by the same initial conditions and macroscopic constraints. The classical example is a gas contained in a container in a state of equilibrium. Strictly speaking, the probability of finding all the molecules in one half of the container is not null, but it is overwhelmingly smaller than the probability of the situations where the molecules are uniformly distributed (except for small random fluctuations). The assumption that the time the system under observation spends in each macrostate is proportional to the probability of this state rests on the hypothesis not only that the system randomly explores all accessible microstates, but that it explores them "quickly enough". As we have seen, for molecules in a gas or in a liquid the typical duration of a given configuration is of the order of one picosecond which means that within the time it takes to make a measurement the system explores over 10^{12} configurations.

No matter how we define the configuration space, it is obvious that it will be explored much more slowly in the case of socio-economic systems. For instance, on stock markets probably one of the economic systems with the highest transition rate, there are on average less than 10 transactions per second even for the most heavily traded stocks. For other socio-economic systems the number of transitions may be smaller by several orders of magnitude. This has at least two consequences. (i) The time it may take for equilibrium to be reached may be large compared to the time scale of human observation. (ii) Consequently, there is a substantial probability of seeing the system in some metastable state rather than in its "true" equilibrium state. As a matter of fact, this problem is not specific to social systems; it also exists for some physical systems such as selenium, sulfur or tin which have different allotropic forms. For instance the transition from white tin to gray tin is

supposed to occur at $13\,^{\circ}$C, but it may take centuries for a plate of white tin to decompose into gray tin even at temperatures as low as $-18\,^{\circ}$C (Kariya et al. 2000, http://www.natmus.dk). Most of the tools developed in statistical mechanics are not well suited to such systems.

7.2 An agenda for future research

One may wonder whether the three manifestations of suicide that we examined can be accounted for by the same mechanism in spite of the fact that they correspond to very different time scales ranging from a few hours to several decades. To try to build a model at this point would probably be premature. If the model "explains" observed suicide rates in terms of social bonds that we cannot estimate in an independent way, this would be no more than a form of circular reasoning. This shows that one of our most urgent tasks is to develop methods for estimating the strength of social interaction. That this objective has so far been largely ignored by sociologists may seem surprising. How, for instance, is it possible to understand revolutions which basically consist in a rearrangement of social networks, if one has no real means for assessing the strength of social ties?

What approach can we think of for that purpose? In physics, experimental methods for measuring the strength of molecular bonds involve infra-red spectroscopy, ultra-sonic spectrography or X-ray/neutron scattering. The three methods are similar in their principle. A wave is sent through the medium and the various ways in which it is affected are recorded and used to probe various characteristics of the medium. The first method is slightly different from the two others in the sense that it relies on the absorption which occurs when the frequency of the source coincides with the stretching or vibration modes of the molecular structure. So far we do not know much about the eigenfrequencies (if any) of socio-economic systems which means that for the time being this is not a straightforward approach. The two other methods have a broader applicability. For instance, in ultra-sonic spectrography an ultra-sonic wave is transmitted through the medium, its velocity and attenuation are recorded, and from these measurements one may derive many properties of the medium, for instance its density, the size of emulsion droplets or the existence of a temperature gradient. At this point, an important requirement needs to be emphasized which is crucial if one wants to extend this approach to the social sciences. In order to be able to use light or sound waves as probes, one must already know how specific characteristics of the medium are likely to affect these signals. In other words, it is only once we have gained some kind of understanding (even if it is only an empirical understanding) of how a given signal is affected by a society that we can use it as a probe. But once this condition is fulfilled, this probe will allow more detailed and systematic explorations. In short, this is a kind of cumulative process where any new knowledge about social interactions is used as a springboard for further explorations.

There are many social signals which should enable us to transpose the previous approach to the social sciences. For instance, the way an epidemic propagates in a society can reveal a lot about the interactions that take place in a population. As an example, one can mention the fact that if two population groups show highly different levels of prevalence for a sexually transmissible disease such as gonorrhea or chlamydia, one can be almost sure that the two groups have little interactions through marriage or non-marital sexual contacts. Such assessments can be checked by confronting them against inter-marriage rates; alternatively, they can replace such statistics in those countries which for some reason do not record that kind of data. Naturally, this example concerns only one particular aspect of social interaction. One would have to develop similar approaches for other aspects as well. The transmission of rumors, innovations or new fashions can provide other possible probes.

In this paper, I tried to convince the reader of the key role of interaction strength in social phenomena. I am convinced that once we get a clearer picture of this factor many socio-economic phenomena will

become more transparent and, to some extent, more predictable.

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